STUDENT'S EDITION

ANCIENT INDIAN KNOWLEDGE IN METALS AND ALLOYS

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INDIAN NATIONAL SCIENCE ACADEMY
NEW DELHI - 110 002

DR. N. GOPALAKRISHNAN

INDIAN INSTITUTE OF SCIENTIFIC HERITAGE
THIRUVANANTHAPURAM - 695 018

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INTRODUCTION

Words of Swamy Vivekananda to youths

Under all these circumstances we find again India reviving and ready to give her own quota to the progress and civilisation of the world. And that I have been forced, as it were, by nature, to go over and preach to America and England is the result. Every one of us ought to have seen that the time had arrived. Everything looks propitious, and Indian thought, philosophical and spiritual, must once more go over and conquer the world. The problem before us, therefore, is assuming larger proportions every day. It is not only that we must revive our own country - that is a small matter; I am an imaginative man - and my idea is the conquest of the whole world by the Hindu race.

There have been great conquering races in the world. We also have been great conquerors. The story of our conquest has been described by that noble Emperor of India, Asoka, as the conquest of religion and of spirituality. Once more the world must be conquered by India. This is the dream of my life, and I wish that each one of you who hear me today will have the same dream in your minds, and stop not till you have realised the dream. They will tell you every day that we had better look to our own homes first and then go to work outside. But I will tell you in plain language that you work best when you work for others. The best work that you ever did for yourselves was when you worked for others, trying to disseminate your ideas in foreign languages beyond the seas, and this very meeting is proof how the attempt to enlighten other countries with your thoughts is helping your own country. One-fourth of the effect that has been produced in this country by my going to England and America would not have been brought about had I confined my ideas only to India. This is the great ideal before us, and every one must be ready for it - the conquest of the whole world by India - nothing less than that, and we must all get ready for it, strain every nerve for it. Let foreigners come and flood the land with their armies, never mind. Up, India, and conquer the

world with your spirituality! Ay, as has been declared on this soil first, love must conquer hatred, hatred cannot conquer itself. Materialism and all its miseries can never be conquered by materialism. Armies when they attempt to conquer armies only multiply and make brutes of humanity. Spirituality must conquer the West. Slowly they are finding out that what they want is spirituality to preserve them as nations. They are waiting for it, they are eager for it. Where is the supply to come from? Where are the men ready to go out to every country in the worlds with the messages of the great sages of India? Where are the men who are ready to sacrifice everything, so that this message shall reach every corner of the world? Such heroic souls are wanted to help the spread of truth. Such heroic workers are wanted to go abroad and help to disseminate the great truths of the Vedanta. The world wants it; without it the world will be destroyed. The whole of the Western world is on a volcano which may burst tomorrow, go to pieces tomorrow. They have searched every corner of the world and have found no respite. They have drunk deep of the cup of pleasure and found it vanity. Now is the time to work so that India's spiritual ideas may penetrate deep into the West. Therefore young men of Madras, I specially ask you to remember this. We must go out, we must conquer the world through our spirituality and philosophy. There is no other alternative, we must do it or die. The only condition of national life, of a wakened and vigorous national life, is the conquest of the world by Indian thought.

At the same time we must not forget that what I mean by the conquest of the world by spiritual thought is the sending out of the life-giving principles, not the hundreds of superstitions that we have been hugging to our breasts for centuries. These have to be weeded out even on this soil, and thrown aside, so that they may die for ever. These are the causes of the degradation of the race and will lead to softening to the brain. That brain which cannot think high and noble thoughts, which had lost all power of originality, which has lost all vigour, that brain which is always poisoning itself with all sorts of little superstitions passing under the name of religion, we must beware of.

Two subjects which are discussed based on the Sanskrit literature are Mathematics and Astronomy . Ancient Indian knowledge in metals and alloys has a history of many millennia. Hence the subject discussion is undertaken in this book by following literature work and metallic artefact obtained from different sites.

It has of great importance and relevance to discuss the modern concepts applied in ancient Indian science, related to metals and alloys. Remarkable evidences have been obtained from the archaeological studies, on the science of metals, described in Sanskrit literature of ancient India. For information on metals and alloys one can go through the authoritative archaeological findings. The most significant base for collecting ancient Indian data on the age of the technology is the C dating technique. Through this technique, any sample can be accurately dated. Hence the dates of production of the old metal samples can be easily found out.

Technological capability in the past.

More than a thousand ancient metallic samples of many millennia old were collected from various sites and subjected to in-depth studies in India and abroad. A variety of Sanskrit books also pour information on this subject, substantiating the knowledge demonstrated in Sanskrit literature with the archaeological evidences. Vedas are the oldest sources of information which are given indirectly. The direct sources are the good number of books in Sanskrit on Chemistry and Ayurveda discussing the metallurgical subject. Susrutha samhita and Charaka samhita gives important information on various

types of metalic surgical instruments used during the period. These two books were written in the first part of the first millennia BC. Artha sastra of Kautilya stands unique, in carrying remarkable information on metals, ores, alloys, and their management in this country. Perhaps no other text gives this much integrated information as the Kautilya's Arthasastra, which was written in the third century, BC. From the available books on chemistry Nagarjuna's Rasaratnakara stands first, which is dated 200 AD. It appears that another Buddhist monk, Nagarjuna has rewritten this book in the 6th Century AD. Bruhatsamhita of Varahamihira written in the early part of the sixth century carries lot of information on this subject. Ashtangahrudaya of Vagbhata belongs to the 8th century A.D. Rasahrudaya and Rasarnava, of Govindabhatta, Rasarnavakalpa, Rasendra choodamani of Somadeva, etc., belong to the period between 9th and 11th century. Rasaprakasasudhakara, Rasakalpa and Rasaratnasamucchaya were written before the 13th century. In fact the study of metals and their products come under the Rasachikilsa, which is considered a part of the Ayurvedic systems. Hence all the Ayurvedic books contain some information on the metals. However, there exist a few books dealing only with the subject of Lohatantra i.e the science of metals.

The Indian capability in metals are directly available from the metal works demonstrated in ancient buildings and temples. These observations are to be correlated with the knowledge that existed in Sanskrit literature. It goes without saying that unless the metallurgical and the alloy making process were known, those metals could not have been mentioned in the ancient books. In Rig Veda (1.122.14) mention is made on a golden ear ring as *hiranyakarnam manigreevam*. A golden necklace is mentioned (1.33.8) as *hiranyayena manina srumbhamaana*. Thus gold as a precious metal was known to the Indians even during (or before) the period of Rig Veda. Sukla Yajurveda (Sukla yajurvedeeya

Vajasaneyee Madhayandina Samhita, 8:13) gives the list of a variety of materials present on the earth in which the metals like iron, gold, silver, copper, lead, and tin are also included.

हिरण्यं च मेऽयिश्चमे सीसं चमे त्रपुश्चमे श्यामं च मे लोहं च मे ।

Hiranyam cha meayaschame seesam chame thrapuschame syaaamam cha me loham cha me

Names mentioned in this texts are syama, hiranya, mehaja, seesa and trapu. Each of these metal has different physical and chemical characterstics and need different types of extraction processes to get them out of their ores. No superfluous knowledge on the ore can give such names for the metals, unless they were produced. All these metals can be obtained by complex processes. Other than the above mentioned stanzas, occasional mention of these metals can be seen in the Yajur Vedic texts. The ores and minerals of metals mentioned in the Vedas are seen in the archaeological location of the Indus Valley civilisation which are the referred Vedic sites. Atharva Veda also carries information on the metals. An interesting stanza (Atharva Veda 11.8.7-8) is the comparison of the colour of the universal power with that of metals:

श्याममय अस्यमांसानि लोहितमस्य लोहितं त्रपु भस्म हरितं वर्णः पुष्करमस्य गन्धः

Syaamamaya asyamaamsaani lohithamasya lohitham thrapu bhasma haritham varna: pushkaramasya gandha:

His flesh has the colour of syama (iron), blood has the colour of loha (copper), totally he has the colour of tin and has the smell of lead. This gives us the message that the metals with that level of purity to be indentified with the exact colour were available during the period of Atharva Veda.

Chandogya Upanishad which is one of the earliest

Upanishads, chronologically coming at par with the Yajurveda period, mention the philosophical approach of knowledge on everything, by citing an example of a metal instrument. This is specifically quoted to highlight its importance as a concept followed in presenting the subject matter in this text, also

नखकृन्तनेन सर्वकर्ष्णायिसं विज्ञातं ...... कृष्णायसं इत्येव सत्यम् ।

Nakhakrunthanena sarvakaarshnaayasam vijnaatham .... krushnaayasam ithyeva sathyam

By knowing the nail cutter all things made of iron become known.......... iron as such is the reality. (Chandogya Upanishad 6.1.6):

Here, the word Krishnayasm is used for iron. This statement throws light on the perfected iron extraction process in the metallurgical studies. Exactly the same words are repeated in the Upanishad to refer to copper as lohamani. (Chandogya Upanishad 6.1.5). It also tells the philosophical approach in literature, even though only a little is given, a lot of information should have to be gathered from it. It is particularly true in case of metallurgical knowledge. As in-depth knowledge of the metallurgical alloying is indirectly presented in the Upanishad (4.17.7) "One would join gold with the help of borax, silver with gold, tin with silver, lead with tin, copper with the help of lead and timber with copper and leather".

तद्र्यथा लवणेन सुवर्णं संदघ्यात्सुवेर्णेनि रजतं रजतेन त्रपु त्रपुणा सीसं सीसेन लोहं लोहेण दारू दोरू चर्मणा

Thadyathaa lavanena suvarnam sandadhyaathsuvarnena rajatham rajathena thrapu thrapunaa seesam seesena loham lohena daaru daaru charmanaa

This is perhaps the best quotable stanza from ancient books on alloying of metals. This is a technique, adopted even now for

reducing the melting point of the metals to be alloyed.

Technological details of metals and alloys can also be discussed with the support of archaeological observations. One of the findings which exist even now is the standing 250 feet, monument in the Singbum copper mine and the 600 feet deep vertical shaft in Hutti gold mines. These two indicate the highest degree of technical competence in ancient mines in India during the Vedic period. Further descriptions are given by Dr. Mukherjee in the Indian Journal of History of science [76].

Ancient Indian Mines: earliest mention of mines appears to be made by Kautilya in Arthasastra. Superintendent of the mines was called Akaaradhaayksha (Arthasastra 2.12.30)

आकाराध्यक्षः शुल्भधातुशास्त्रपाकमणिरागजज्ञस्तज्जज्ञासखो वा
तज्जातकर्म करोपकरणसंपन्नः किट्टमुषांगारभस्मलिंगं वाकरं
भूतपूर्वमभूतपूर्वं वा भूमिप्रस्तररसधातु मत्यर्थवर्ण्णगौरवमुग्रगन्धरसं परीक्षेत ।

Aakaaraadhyaksha: sulbadhathu saasthrapaakamaniraaga jijnasthajjajnasakho vaa thajjaatha karma karopakarana sampanna: kittamooshangaarabhasmalingam vaakaram bhoothapoorvamabhootha poorvam vaa bhoomi prasthara rasa dhatumathyartha varnna gourava mugragandha rasam pareekshetha

The director of mines is responsible for the ores, minerals, chemicals, etc. He should have the knowledge of these things and he is responsible for the examination and utilisation of three types of ores. Bhoomi-prastara-rasa dhatus (ores of three types). He has to know the quality of ores by means of colour, smell taste, acidic-alkaline and -textural tests.

The metals obtained from mines are said to be gold, silver etc., and diamonds (Arthasastera 2.6.4). It is also said that the treasury has its source in mines, from treasury, the army comes into being. With the treasury and the army, land is obtained.

With the treasury as its ornament is, the mines. (2.12.37). Twelve kinds of metals obtained from the mines are mentioned in Arthasastra (2.12.23 and 35, 36)

In Arthasastra, the melting process is given as dravana (3.3.27). Melting of the metals was also known as Vipalana. and the term is particularly used for iron and copper. Solidification of the metal is described as mruthi. Heating is the most important processing in alloying metals. It is thus said:

नाऽतप्तं लोहं लोहे न सन्धत्ते

Naathaptham loham lohe na sandhatthe

Without heating metals cannot be alloyed.

C_{14} carbon studies conducted by the metallurgists have shown that ancient mines used for the production of silver, tin, copper, lead and zinc were seen in many locations. A few among most ancient are mentioned here. Some of the metallic samples obtained from the sites are two thousand to three thousand years older than the periods given below. Dates given below are the most active period of the production of metals from these mines.

Rajapura, Dariba, Udaipur in Rajastan	1300 BC
Hatti in Karnataka	1000 BC
Rampura, Agucha	700 BC
Zawarmala and Ambamata in Rajastan	500 BC

Iron was extracted from the following mines.

Komaranahalli and Tadanahalli in Karnataka,	1300 BC
Atranjikhera	1200 BC
Pandu Rajar Dhibi in Bengal	1300 BC
Alamgirpur in Rajastan	1000 BC
Varnasi	1000 BC

Descriptions of Mettallic Ores and Minerals: Ores and minerals are the natural metallic compounds present in the earth. There are a variety of such compounds from which the respective metals can be extracted. Arthasastra is the most authentic ancient text book describing the ores of metals. Arthasastra (2.12.30):

पीतकास्ताम्रपीतकाभूमिप्रस्तरधातवो भिन्ना नीलराजीमन्तो
मुद्गमाषकृसरवर्णा वा दधिभिन्दुपिण्डचित्राहरिद्राहरीतकी
पद्मपत्रशैवलयकृत् प्लीहानवद्यवर्ण्ण भिन्नाश्चुञ्जजुवालुका
लेखाभिन्दु स्वस्तिकवन्तः सगुलिका अर्चिष्मन्तस्ताप्यमाना न भिद्यन्ते
बहुफेनधूमाश्च सुवर्णधातवः प्रतीवापार्थास्ताम्ररूप्य वेधनाः

Peethakaasthaamra peethakaa bhoomiprastharadhathavo bhinna neelaraajimantho mudga maasha krusara varnaa vaa dadhi bhindu pinda chithraa hari draahareethakee padmapathra saivalayakruth pleehaanavadyavarnna bhinnaaschujnajuvalukaa lekhaabindu svasthikavantha: sagulikaarchishmanthasthaapya maanaa na bhidyanthebahuphena dhumaascha suvarnadhathava: pratheevaapaarthaa sthaamraroopya vedhanaa:

The colour of different ores can be yellow, mixed yellowish red, when cut, it can be bluish colour of green gram, black gram, curd, turmeric, terminalia seeds, liver of animal, spleen sand, jasmine bud, seed of neem. Some of the ores when burnt remains the same and Surf is formed in some cases. These descriptions agree well with the information available on minerals and ores of the metals.

Description of silver ores:

शङ्ककर्पूरस्फटिकनवनीतकपोतपारावत विमलकमयूरग्रीवावर्णाः
सम्यक् गोमेदकगुडमत्स्यण्डिकवर्णा कोविदारपद्मपाटलीकलाय
क्षौमातसीपुष्पवर्णाः ससीसाः सो जनाविस्रा भिन्नाः श्वेताभाः कृष्णाः

कृष्णाभा: श्वेता: सर्वे वा लेखाबिन्दुचित्रा मृदवोध्माय मानान स्फुटन्तिबहुफेनधूमाश्च रुप्यधातव: सर्वधातूनां गौरववृद्धौ सत्ववृद्धि:

Sankakarpooora sphatikanavaneetha kapotha paaraavatha vimalakamayooragreevavarnaa: samyak gomedaka guddamathsyaandika varnaa kovidaarapadma paataleekalaaya kshowmaathasee pushpavarnaa saseesa: so yanaavisraa bhinna: sethaabhaa: krishnaa: krishnaabhaa: svethaa: sarve vaa lekhabindu chithraa mrudvodhmaaya manaana sphutanithi bahuphena dhoomaascha roopyadhaathava: sarvadhaathoonaam gouravavruddhow sathvavruddhi:

Native silver ores are of 18 types. They are classified on the basis of colours: colour of conch shell, camphor, pearl, jewel, jaggery, lotus flower, etc. Some times they get mixed with lead. Some are white outside and black inside. Smoke comes out when burnt. In all the minerals the density increases with the metal content in them These observations agree well with the qualities noted for silver ores available from different part of North India.

Description of copper ore: Copper ore is explained in Arthasastra (2.12:30)

भारिक: स्निग्धो मृदुश्च प्रस्तरधातुर्भूमिभागो वा
पिङ्गलो हरित: पाटलो लोहितो वा ताम्रधातु:

Bhaarika: snigdho mruduscha prastharadhaathur bhoomibhaago vaa pingalo haritha: paatalo lohitho vaa thaamradhaathu:

This can be translated as Heavy, tawny, green (Chalcopyrite ore) dark blue (malachite ore) yellowish tint (azurite) pale red or red (native coper) are the ores (dhatus) of copper. The explanation given in Arthasastra agree well with the characterstics of the ores of copper given in bracket.

काकमेचक: कपोतरोचना वर्ण: श्वेत राजिनधो वा विस्र: सीसधातु:

Kaakamechaka: kapotharochanaa varna: svetha raajinidho vaa visra: seesadhaathu

Lead ores are explained by Kautilya (2:12:30). It is greyish black like kaka mechaka, (galena ore), yellow like pigeon bile (gossam ore), etc. The characterstics agree with galena and gossam ore of lead.

Description of Tin ore: Tine ore is as grey saline or like brown burnt earth (cassiterite) (Arthasasthra (2.12.30)

ऊषरकर्बुर पक्वलोष्टवर्णो वा त्रपुधातु:

Usharakarbura padvaloshtavarno vaa thrapudrathu:

Description of Iron Ore: Iron ore is explained (Arthasasthra 2.12.30) thus:

सुरुम्ब: पाण्डुरोहित: सिन्दुवारपुष्पवर्णो वा तीक्ष्णधातु:
काकाण्डभुजपत्रवर्णो वा वैकृन्तकधातु:

Surumba paandurohitha: sinduvaarapushpavarno vaa theekshna dhaathu: kakaanda bhujapathravarno vaa vaikrunthaka dhaathu:

Greasy stone, pale red, colour of orange limonite or Sindudrava flower (Hematite). The ore which has the colour of crow egg or birch leaf is vaikruntaka ore (magnetite).

The qualities attributes to these ores are identified and found correct. On the technology aspects also Chanakya has given descriptions. In Arthasastra he has mentioned that the Director of metals (Lohaddhyaksha) should establish factories for the production of metals and alloys like copper, lead, tin, vaikruntaka, arakuta, brass and steel, bronze, tala (bell metal) and loha from the corresponding metal ores. All the business related to metals also should be undertaken under his supervision (Arthasastra 2.12.30)

लोहाध्यक्षः ताम्रसीसत्रपुवैकृन्तकार कूटवृत्तकंसताल
लोहकर्मान्तान् कारयेत् लोहभाण्डव्यवहारं च

Lohaadhyaksha: thaamra seesathrapu vakrunthakaara kootavrutthakamsathaala loha karmaanthaan kaarayeth lohabhaanda vyavahaaram cha

An integrated knowledge of the mines, ores and the metal processing that existed in the time of Kautilya, i.e 350 years before Christ, is reflected)

Impurities in Ores: Other than the specific metallic compounds present in the ores, there can be a variety of attached impurities too. Mention of these impurities is also made in the Arthasastra text, "thus some of the impurities are attached firmly with the ore. They can have intense smell and may be alkaline in nature. These impurities are to be mixed with other things and burnt off for removal". In modern metallurgy the organic matter present in the ores is burnt and inorganic impurities are converted into slag and removed from molten metal.

Furnaces and kilns: Different varieties of furnaces and kilns were used in earlier days for the extraction of metals from their ores. A furnace or kiln is defined according to the process taking place in the furnace. In Sanskrit the furnace/kiln is known as Musha, which is defined as follows:

मुष्णाति दोषान् मूषेयान् सा मूषेति

Mushnaathi doshaan moosheyaan saa mooshethi

The vessel which removes or destroys the impurities is known as Musha.

Furnaces are made of special types of sand as followed in modern technology. The quality of the sand used for making furnaces has been defined as follows:

मृत्तिका पाण्डुरस्थूल शर्करा शोणपाण्डुर चिराध्मानसहासाहि
मूषार्थमतिशह्यते ।।

Mrutthikaa paandurasthoola sarkaraa sonapandura chiraadmaana sahaasaahee mooshaartha mathisahyathe

Yellowish white and heavy sand or reddish white sand that can withstand high temperature for a long time, is the best for the manufacture of Mushas/kilns and furnaces. Different varities of furnaces used for specific purposes are named in Rasaratna samuchaya:

वज्र योगवज्रद्रावणिगारवरवर्णरुप्यविडवृन्तक गेस्तनि
मल्लपक्वगोलमहामाण्डूक मूशलमूषा ..... ।।

Varja-yoga-vajradravani-gara-vara-varna-roopya-vida vruntaka-gostani-malla-pakwa-gola-maha-maanduka-musala are the common furnaceskilns

For extraction, purification and alloy making, suitable furnaces and kilns from among this list are used. Furnaces mentioned here are of different sizes, shapes and for different purposes.

The temperature for extraction of metal is attained according to the nature of the metals and ores. The process is sometimes called Kupeepaka vidya. And the process adopted for getting different levels of heat is by using putas which are generally cubical in shape. All these putas are able to provide an average temperature of 750° - 900°C. The duration of maintaining the temperature and the dimensions of these putas are given below:

Mahagajaputa furnace	: 36 width x depth.		Duration	150 min
Gajaputa furnace	: 22 ½	"	"	100 min
Varahaputa	: 16	"	"	50 min
Kukkutaputa	: 9	"	"	5 min
Kapota puta	: earth surface		"	Low tenperature

The above types of putas were made using cubical arrangement of cow dung cake. For example in mahagajaputa, 2000 cow dung cakes were arranged and for other putas 1000, 800, 40 and 8 cakes respectively were used. The number of cakes used depend upon the final temperature required and the duration upto which the temperature are to be maintained. And this in turn depends on the metal which is to be processed. Every puta has a definite specificaiton to follow. This definitely is the modern approach followed in metal technology. The above temperature values attainable have been recently reported by experimenting with modern instruments for each putas, based on the information given in Rasaratna samuchaya.

Interestingly in the above mentioned archaeological sites many furnaces/kilns, of measurements ranging from one ft high to 7ft high and internal thickness upto 1.5 ft were seen. These kilns had been in use during the periods from 2000 BC onwards.

Qualification of pure metals: Each metals has specific colour, texture and nature. But while producing these metals, the purity was judged by following general characteristics, which were also known to ancient Indians.

The qualification of pure metal is defined correctly in Rasarnava (52-55)

न विस्फुलिंगा न च बुद्बुदाश्च यदा न रेख पटलं न शब्दः ।
मूषागतं रत्नसमं स्थिरश्च तदा विशुद्धम् प्रवदन्ति लोहं ।।

Na visphulingaa na cha budhbudaascha yadaa na rekha na sabda:
mooshaagatham ratnasamam sthirascha thadaa visuddham
pravadanthi loham

Pure metal is that which when melted in crucible does not give sparks nor bubbles, nor spurts, nor emits any sound nor

shows any lines on the surface, but is tranquil like gem and this pure metal flow out, from furnace.

This definition stands correct, because all the above qualification are possible only if impurities are absent in the molten metal, at that temperature.

Use of flux to remove impurtiry as slag: Metals and impurities are difficult to melt directly during the metallurgical process. Flux, which is a foreign material, is added to remove the impurities as slag. This process was known earlier.

दुर्द्राव अखिल लोहादे: द्रावणाय गणो मत:

Durdraava akhila lohade: dravanaaya ganomathai:

It is mentioned that, to aid melting of otherwise difficult to melt metals / impurities, lower fusing materials are added (Rasaratna samucchaya 10.95)

A variety of fluxes have been used to convert impurities into slags. These slags were obtained from almost all the mine sites where lead, tin, copper and iron were extracted. Their period of production has also been estimated. One such archaeological site is the Rajghat copper mines. Large amount of slag was present there, which contained 5.4% calcium oxide. The calcium oxide was specifically brought from far away places to this location for the specific purpose. It is not available nearby places. The technology of use of calcium oxide to remove the impurity was the same as that followed in modern processes. Calcium oxide is used as flux to remove the silicon dioxide by converting into calcium silicate. Once, the slag is discarded major portion of the impurities from the metal is removed. This gives reasonably pure metal, which can be further purified or alloyed. The quality of the technology adopted in the metallurgical process can be appreciated only if the percentage purity of the metal obtained is compared.

Purity level of ancient Indian metals : A few examples.

copper	-	Nalanda	97.9%
copper	-	Mohan jodara	97.1%
copper	-	Atranjikhera	97.3%
silver	-	Mohan jodaro	94.5%
lead	-	Mohan jodaro	99.7%
copper in alloy	-	Harappa	98.8%
nickel in copper alloy	-	Taxila	21.0%
lead	-	Lothal	99.5%
copper	-	Harappa	99.0%
bronze	-	Taxila	85% copper/9.8%tin
brass	-	Taxila	55.4% copper/34.3% zinc

The archaeological sites noted above were active metallurgical centres/cites between 300 BC to 3000 BC. Majority of these centres existed around 3000 BC and period Lothal was 2200 BC.

Purity of the above mentioned metal samples are very high. Lead with 99.7% purity could be produced in Mohan jodaro. Similarly other metals, from this one can imagine the technological capability existed.

Thus archaeological evidences of a variety of kilns, knowledge on production of high temperature, use of flux, absolute quality of pure metal, are all in full agreement with what is given in the Sanskrit literaure on the science of metals and ores.

Corrosion of metals : Degradation of metals by way of atmospheric reactions with oxygen, moisture, acidic or alkaline materials are natural phenomena. The knowledge of this subject was existing in India. This is generally termed as corrosion study, in modern science. This is mentioned in Rasarnava (7.89-90)

सुवर्णं रजतं ताम्रतीक्ष्णवंग भुजंगमाः
लोहकं षड्विधम् तच्च यथापूर्वं तदक्षयं

Suvarnam rajatham thaamra theekshna vanga bhujangamaa;
lohakam shadvidham thachha yathaapoorvam thadakshayam

Gold, silver, copper, iron, lead and tin are the six types of metals which undergo self corrosion at a slower rate in the reverse order of this arrangement.

I.e gold is the least corroding and tin the fastest corroding among the six metals mentioned here. Corroded impurities formed on the surface of metals such as oxides, hydroxides, carbonates, etc., are removed by washing with acidic or alkaline solutions. Present day application is also in line with the above knowledge. Yajnavalkhya smruti (Acharadhyaya 190(8) refers to the cleaning of the metals.

त्रपुसीसकताम्राणां क्षाराम्लोदक वारिभिः भस्मादि
कांस्यलोहानां शुद्धि प्रावोद्रवस्य च ।।

Thrapuseesaka thaamraanaam kshaaramlodaka vaaribhi:
bhasmaadi kamsyalohaanaam suddhi praavodravasya cha

Tin, lead, copper, may be cleaned with alkali and acids. Iron, bronze and copper alloys are cleaned with ash and water.... The use of acids and alkalies readily decomposes the corroded impurity from the surface of the metals and cleanse the metals.

Alloy making:

The Indian authority on the production of the alloys has been well appreicated from time immemorial. Living examples are available throughout India, in the buildings and temples where a variety of metallic alloy have been utilised, like bronze and other alloy. Ashoka is said to have installed 85000 statues of which 30% are made of metals. In South India, a variety of

Panchaloha idols were made, which have an unusual composition of a variety of metals [79].

Arthasastra says that the coins are manufactured using different metal alloys. The nature of alloys in coins are described in lines 2,12:30 of Arthasastra

लक्षणाध्यक्षा: चतुर्भागताम्रं रुप्यरुपं तीक्ष्णत्रपुसीसाञ्जानानामन्यतमाषबीजयुक्तं कारयेत् । पणं, अर्धपणं, पादमष्टभागमिति ।।

Lakshanaadhyakshaa: chathurbhaaga thaamram roopyarooopam theekshna thrapuseesaa jnaanaanaamanyatha masha beejayuktham kaarayeth, panam ardhapanam paadamashtabhaagamithi

The Director of coins should know how to make four types of coins: i.e one pana, half a pana, one fourth and one eighth of a pana using copper, silver, lead, iron and if required other metals.

Further, Kautilya explains the alloying of metals to make the coins and their denominations (Arthasastra 2:12:30)

पादाजीवं ताम्ररूपं माषकमर्धमाषकं काकणीमर्धकाकणीमिति ।।

Paadaajeevam thaamraroopam mashakamardha maashakam kaakaneemardhakaakaneemithi

The above statement when analysed using the explanations given in the commentary on the metallic compositions gives this meaning: Padajeeva type of copper coin contains 4 parts of silver and 11 parts of copper and 1 part of any metal like iron, tin, lead or antimony. This coin is known as Mashakam. Half of this composition is known as ardha mashakam, One fourth of this gives kakani, one eighth of this is ardha kakani.

This gives proof good on knowledge on alloy making process for the manufacture of coins, which is one of the sophisticated techniques adopted for getting uniform, size, shape, weight and quality coins

Specific metallic alloys

Bronze: Bronze is one of the most common and important alloys used in India. Archaeological information available on the bronze is plenty. Bronze and brass are the two alloys obtained from almost all the excavated sites. This shows that, preparation of alloys was very familiar throughout this continent. Vedas also give the descriptions of this alloy. The most common alloys used in temples of South India were bronze and brass as statues, vessels or decorated backgrounds of the structures. Specific descriptions on bronze and brass can be seen in Panini's Astaddhyayee (8.2.3.1) in which the bronze vessels are discussed:

बहुक्षीरघृतमोदनम् कांस्यपात्र्यं भुञ्जीरन्निति

Bahuksheeraghrutha modanam kaamsyapaathryam bhunjeerannithi

Brass and bronze vessels can be used for storing ghee, milk, etc.

Panini was a contemporary scholar of the ruler Pushyamitra Sunga (187 BC). This line gives the information on the use of copper alloy. Earlier to Panini, the author of Arthasastra, Kautilya has described bronze while commenting on the duties of the lohaddhyaksha, which is mentioned earlier (2.12.30). Rasaratna samucchaya (5.205) gives the composition of one type of bronze.

अष्टभागेन ताम्रेण द्विभाग कुटिलेन च विद्रुतेन भवेत् कांस्यम्

Ashtabhagena thamrena dvibhaaga kutilenacha
vidruthena bhaveth kaamsyam

Eight part by weight of copper and two part by weight of tin gives the best bronze. Archaeological observation shows that bronze obtained from Lothal has 11-12% tin in it. A variety of bronze tools obtained from Mohanjo daro has copper content ranging 80 - 90% correspondingly, the remaining part is tin.

Brass : As in the case of bronze, the explanations on brass in

Sanskrit literature and also the nature of ancient brass samples give ample proof that the metallurgical knowledge of this alloy was millennia older than even Christian era. Zinc is also called suvarnakara because it converts copper into gold like alloy, which is brass. Earlier quotations given from Arthasastra carries information on brass. Brass was made in India by directly alloying the copper with zinc and also by alloying copper with zinc ores.

Brass alloy making observation is thus described. (Rasaratnakara 3)

किमत्रचित्रं रसको रसेन ..... क्रमेण कृत्वाम्बुधरेण रंजित:
करोति शुल्वं त्रिपुटेन काञ्चनं

Kimathra chithram rasako rasena kramena kruthvaambudharena ranjitha:karothi sulvam thriputena kaanchanam

What wonder is that calamine (zinc ore) roasted thrice with copper convert the latter into gold (actually brass)

The procedure explained here is the indirect alloying of copper with zinc ore. The decomposed zinc ore and separated metal zinc, directly but slowly alloys with copper and brass is formed. Modern studies have shown that the maximum content of zinc (from calamine) that can alloy with copper under this condition is 28% (i.e from the zinc ore). Ancient brass materials have shown that the majority of the samples obtained, contained less than 28% of zinc. This may be due to the fact that, those brass samples might have been prepared from zinc ore and copper metal. Alloying the zinc directly with copper has also been discussed in Rasarnava (7.34-38)

सत्वं कुटिलसंकाशं करोति शुल्वं त्रिपुटेन काञ्चनं

Satvam kutilasankaasam karoti subram thriputena kaanchanam

Zinc, a metal like tin converts copper into gold.

Here the use of the term gold is for brass. Panini in

Ashtaddhyayee has mentioned Suvarnakara for the tin/zinc (5.1.30) while discussing the coins made of copper or tin by alloyings with zinc.

Brass samples from Lothal had the composition of 6.04% zinc and 70% copper. This brass belonged to the period of 2200 BC. The earliest brass piece containing more than 28% zinc was obtained from Taxila, the period of which is 4th century BC. This brass was prepared by directly alloying copper and zinc metal instead of zinc ore (calamine) become more than 28% zinc was present in it.

Rasaratna samuchhaya (5.191-193) gives description on brass

रीतिका काकतुण्डी च द्विविधं पित्तलं भवेत् ।
सन्तप्ता कांजिके क्षिप्ता ताम्राभा रीतिका मता ।।
एवं या जायतेकृष्णा काकतुण्डीति सा मता ।
गुर्वीमृद्वि च पीताभा सरंगी ताडनक्षमा ।।

Reethikaa kaakathundee cha dvividham pitthalam bhaveth
Santhapthaa kaanchike kshipthaa thamraabhaa reethikaa mathaa
evam yaa jaayathekrishnaa kaakathudeethi saa mathaa
gurveemruddhi cha peethaabhaa sarangee thaadanakshamaa

Brass is of two kinds reetika and kakatundi. The former when heated and plunged into sour gruel turns into copper coloured and the latter one turns black. The former is heavy, soft, yellow, resistant to hammering, brilliant and smooth.

This explanation stands as far as the qualification of brass is concerned. The brass which contains less than 28% zinc has the above said property.

This brass according to modern terms is alpha brass. Whereas the second one contains more zinc in it. It should have different properties from that of alpha. Mention of crow colour

(Kakatundi) can be due to the blackening of brass containing a traces lead present in zinc.

These descriptions throw light on the highly scientific approach followed in alloy making. The observation made on the post processing of brass by treating with sour gruel is a quality analyses parameter of brass.

Bell metal : Sound of the bell has been sacred for all Indian rituals. It is mentioned that by making the sound of the bell, the gods are invoked. For making a bell, one should know the technology of bell alloy making. Unlike the qualifications required for other metal alloys, the bell metal should give a perfect, melodious and acceptable musical sound. Hence this alloy preparation attracts special attention of metallurgists. Bell metal is a copper alloy mentioned in Arthasastra as tala. Method for separating copper from bell metal is described in Rasaratna samucchaya (8.37)

स्वल्पतालयुक्तं कांस्यम् वंकनालेनताडितं मुक्तरंगं
हि तत् ताम्रं घोषाकृष्टं उदाहृतं

Svalpathaalayuktham kaamsyam vankanaalena thaaditham muktharangam hi thath thaamram ghoshaakrushtam udaahrutham

Molten bell metal is heated with a little tala or orpiment blown with a bent tube and freed from Ranga of tin What we get is bell metal extracted copper. The word ghoshakrushtam is specific for the sound making alloy which is now known as bell metal. Even in Vedas bells have been mentioned frequently. Millennia old bells can be seen in many temples.

Panchaloha: This is the most common alloy used in the manufacture of idols. For the last three thousand years Panchaloha (which literally means five metals) was used for

making idols. Panchaloha idols with a historical background of two millennia could be excavated by archaeologists. Many ancient Sanskrit and regional literature are important sources of information on this alloy making. The artists who perfected this technology are many in South India. The traditions have been maintained and nurtured for centuries. Charaka samhita gives the explanation of Panchaloha as follows (1.70)

सुवर्ण समला: पञ्चलोहा: ससिकता: सुधा ।
मन: शिलाले मणयो लवणं गौरिकाञ्जने ।

Suvarna samalaa: panchaloha: seesakathaa: sudhaa
mana: silaale manayo lavanam gouri kaanchane

In Panchaloha, gold and separately copper, silver, tin, lead and iron are mixed. Its composition is also described as follows:

कांस्य अर्करीति लोह अहिजातं तत् पर्तलोहकं तदेव
पञ्चलोहाख्यं लोहविद्भि: उदाहृतं ।

Kaamsya arkareethi loha ahijaatham thath parthalohakam
thadeva panchalohaakhyam lohavidhi udaahrutham

An alloy of five metals of tin, copper, brass, iron and lead is panchaloha (Rasaratna samuchaaya (5.212).

Metal seal : Bruhat samhita (57-17) gives this explanation to the metal seal:

अष्टौ सीसकाभागा: कांसस्य द्वौ तु रीतिकाभाग:
मयकथितो योग: अयं विज्ञेयो वज्रसंघात:।।

Ashtow seesakabhagaa. kaamsasya dow thureethikaa bhaaga:
mayakathitho yoga: ayam vijneyo vajrasanghaatha:

Eight part lead, two part bell metal and one part brass alloy has been described by Maya as the Vajrasanghatha metal seal.

In modern metal science metallic seal is commonly used.

Pure metals

Copper : Copper is one of the most common metals known to human race. Tamra is the word adopted in Yajurveda for copper. Historically the copper age has been given importance on the basis of the technological capability in the progress of human civilization. Keeping away the literature, one can see that historically copper metallurgy is the oldest in India. Mehargarh excavation showed that the copper samples extracted belonged to 8000 BC. One of the many samples obtained from this site has recorded the production date which can be 7786 +/- 120 BC i.e 10000 years back! The number of copper and copper alloy samples obtained from various archaeologically important sites were about 2500 BC.

As far as the Sanskrit literature is concerned, it appears that Arthasastra comes first in the descriptions of copper. The earlier mentioned are the description of ores of copper by Kautilya in Arthasastra. All the 'pana' coins inevitably contained copper as the major component. Mashakam contained 11 parts by weight of copper (4 parts silver and 1 part other metal). Harappan copper was 99% pure and Mohanjo daro copper 97%. Ancient technology should have been excellent to get this level of purity for the copper.

Interestingly, copper kilns used during the post Vedic period can be seen in the mine sites even now. Kiln residue obtained from many sites showed that removal of iron from copper, during the extraction of the latter was carried out by adding the flux. Large amount of iron silicate could also be seen. This shows that the copper extraction method followed was technically high standard.

Iron : Evidences available from Mesopotamia, Egypt, and Afghanistan show, that during 3000 - 2000 BC efforts were made to produce iron. Similar trails were conducted in Cyprus during 1600 B C [80]. Upto 1600 BC the Greek and the Mediterranean

people could not produce iron. After putting all the evidences together, it was concluded that till 1200 BC iron production was not conducted successfully anywhere in the world. But in Yajurveda mention of iron as syamam can be seen.

In Susrutha and Charaka samhita, use of iron to treat anaemia as an asavam (tonic) is mentioned. This asavam is known as Loha asavam. It is described as follows:

युक्तानि लोहवत्कुम्भे स्थितानि घृतभाविते
संवत्सर निधेयानिवपल्ले तथैव च ......

Yukthaani lohavathkumbhe sthithaani ghruthabhaavithe
samvatsara nidheyaaniapalle thathaiva cha....

For years together, ghee is stored in iron vessel and that is used for the preparation of iron asavam.

Archaeological samples obtained from five regions of North India shows that by 1200 BC iron was commonly produced in India. One sample obtained from Ahar was dated at 1300 BC. C_{14} carbon dating studies showed that iron samples obtained form Leobarn, Pirak, Hallur, Tamragarh, Atranjikhera were produced between 1600 - 1300 BC. The use of iron for making alloy is discussed in Arthasastra. Iron ores, probably hematite and magentite have been described in detail in this book. They are Surumba and Vaikruta dhatus. Their colour and texture resemble perfectly with the ancient explanations and modern observations.

मुण्डं तीक्ष्णं च कान्तं च त्रिप्रकारमयस्मृतं

Mundam theekshnam cha kaantham cha thriprakaaramayasmrutham

Three important classes of iron has been mentioned in the text books of Maya,Kanta Loha, Teekshana Loha and Mundaloha. (Rasaratnasamuchhaya 69)

भ्रामकं चुम्बकं चैव कर्षकं द्रावकं तथा एवं

चतुर्विधं कान्तं रोमकान्तम् च पञ्चमं ।

Bhraamakam chumbakam chaiva karshakam dravakam
thathaa evam chathurvidham kaantham romakaantham chapanchamam

Kanta Loha, which is soft iron, has the following five categories: bhramaka, chumpaka, karshaka, dravaka and roma (Rasaratna samuchhaya 84)

... षड्विधं तीक्ष्णमुच्यते .. खरलोहमुदाहृतम् .. सारलोहं तदीरितम् ..

Shadvidham theekshnamuchyathe ..... kharalohamudaahrutham
.... saaraloham thadeeritham

Teekshna loha (which is carbon steel according to modern definitions), are of six types: khara, hrunnala, trivrutta, vajra, kala., etc. (Rasaratna samuchhaya 75)

मृदु कुण्ठं कडारं त्रिविधं मुण्डमुच्यते

Mrudu kuntam kaddaram thrividham mundamuchyathe

Mundaloha which is the cast iron is of three kinds: mrudu, kunda and kadara. The quality of roasted iron and rust of iron is compared here. This gives a very important information of the knowledge similar to chemical composition of both of the compounds as iron oxide (Rasaratna samuchaya 148)

ये गुणामारिते मुण्डे ते गुणा मुण्डकिट्टके
तस्मात् सर्वत्र मुण्डरं रोगशान्त्यै प्रयोजयेत् ।

Ye gunaa maarithe munde the gunaa mundakittake
thasmaath sarvathra mundaram rogasaanthyai prayojayeth

The qualities of air-roasted iron and the rust of iron are the same. Therefore the latter was also acceptable for medicinal purposes.

Bruhat samhita (50.26) explains the method of carburisation of iron. Carburised iron weapons were spotted in many places

by the archeological study groups. The process of carburisation gives hardness and sharpness for weapons. This subject has been discussed in detail by Bhatia [80b].

क्षारे कदल्या मथितेनयुक्ते दिनोषिते पायितमायसं यत् सम्यक् शितं
चाश्मनि नैति खड्ग न चान्यलोहेषु अपि तस्य कौलठयम्

Kshaare kadalyaa mathithenayukthe dinoshithe paayitha
maayasam yath samyak sitham chaasmani naithi
khadga na chaanyaloheshu api thasya kowlatayam

The iron weapon treated with a day old banana drink made of burnt powder of bananas mixed with butter milk and then sharpened properly, will not break in stones, nor becomes blunt on other instruments.

The quality of Indian steel has been referred to by Ktesias who was in the court of Persia in the 5th century BC. Swords made in India were purchased by Persian kings. Alexander the great was said to have received 30 pounds of Indian steel in 326 BC from King Porus for making Damascus swords.

Iron metallurgical process and alloy preparations in ancient India was common. Iron is the common metal known to have the highest melting point nearly 1500° C. Indians could achieve this temperature level for iron processing. Nowadays coal is used for the purpose whereas in ancient period, fuel combinations used for achieving this temperature is yet to be found out.

Silver : Metallurgical process of Silver was known at least from the period of Mohanja daro civilization. Silver articles were obtained from there. Arthasastra describes silver as follows: (2:13:31)

तुत्तोद्गतं गौडिकं काम्बुक चाक्रवलिकं च रूप्यं श्वेतं स्निग्धं मृदु
च श्रेष्ठं विपर्यये स्फोटनं च दुष्टं तत् सीस चतुर्भागेन शोधयेत्
उद्गत चूलिकमच्छम् भ्राजिष्णु दधिवर्णम् च शुद्धम् ।।

Thutthodgatham gouddikam kaambuka chaakravalikam
cha roopyam svetham snigdham mrudu cha sreshtam
viparyaye sphotanam cha dushtam thath seesa chathurbhaagena sodhayeth
udgatha choolikamaccham bhraajishnu dadhivarnam cha suddham

Silver has the colour of jasmine bud, it contians a lot of lead, it may have the colour of sky, it is white, soft and also precious. If mixed with 4 parts of lead, the alloy will have the colour of fresh curd.

Arthasastra also describes the purification of silver (2:13:31)

तारमपशुद्धम् वा अस्थितुथे चतुः समसीसे चतुः ।
कपाले त्रिः गोमयद्विः! एवं सप्तदशतुत्थातिक्रान्तम्
सैन्धविकयोज्चालितं एतस्मात् काकण्युत्तरा, पसारिता .....
Thaaramapasuddham vaa asthithutthe chathu: samaseese chathu:
kapaale thri: gomayadi evam saptha dasathuththaathikraantham
saindavi kayojvalitham ethasmaath kaakanyuttharaa pasaarithaa...

Impure silver is mixed with bone powder, 4 parts lead, 4 parts sand, 4 times cow dung, 3 parts kopal together 17 parts, mixture is taken in a kiln. It is heated and mixed with salt and sand and further melted. To the silver, thus obtained some gold is also added for getting shining appearence.

This is the actual process adopted for the removal of impurities such as lead, iron, etc. from the silver during its extraction process. Impurities or 'adulteration' of silver has been explained based on physical characteristics, in Arthasastra (2:14:33)

रजतानां विस्रं मलग्राहि परुषं प्रस्तीतं विवर्णम् वा दुष्टमिति विद्यात् ।
Rajathaanaam visram malagraahi parusham
prastheetham vivarnam vaa dushtamithi vidyaath

If silver happened to be mixed with lead, it will have a bad smell. The alloy will be rough, less coloured, low shining, etc.

This silver is to be purified with the bone powder in a furnace.

The science behind this process says that the addition of bone gives the source of calcium to remove the impurity to convert them as calcium salts. Detailed description of silver alloys are given in the above chapter as follows (Arthasastra 2:13:31)

त्रयोंऽशास्तपनीयस्य द्वात्रिंशद्भागश्वेततारमूर्च्छितं तत् श्वेतलोहितकं भवति ताम्रं पीतकं करोति । तपनीयमुज्वाल्य रागत्रिभागं दद्यात् पीतरागं भवति श्वेततारभागौ द्वावेकस्तपनीयस्य मुद्रगवर्णं करोति कालायसस्यार्द्धभागाभ्यक्तं कृष्णं भवति प्रतिलेपिना रसेन द्विगुणाभ्यक्तं तपनीयं शुकपत्रवर्णं भवति तस्यारम्भे रागविशेषेषु प्रतिवर्णिकां गृह्णीयात्

Thrayoamsaasthapaneeyasya dvaathrimsath bhaaga svethathcaamoorcchitham thath svethalohithakam bhavathi / thaamram peethakam karothi thapaneeya mujvaalya raagathribhaagam dadyaath peetharaagam bhavathi svetha thaara bhaagow dvaaveka sthapaneeyasyaa mudragavarnam karothi kaalaaya sasyaarddha bhaagaabhyaktham krishnam bhavathi prathi lopinaa rasena dvigunaabhyaktham thapaneeyam sukapathravarnam bhavathi thasyaarambhe raagavisesheshu prathi varnikaam gruhneeyaath

Three parts of copper and 28 parts of silver give silver with sweta lohita colour . Three parts gold and 28 parts silver give silver with peetha raga colour. Two parts of silver and 1 part of gold give silver with mudga (green gram) colour. Two parts silver, 1 part gold and 1/6 iron gives silver with blackish colour. This alloy mixed with mercury gives silver with golden bird's feather colour.

रूपस्य द्वौ भागावेकः शुल्बस्य त्रिपुटकं तेनाकारोद्गतमपसार्यते तत् त्रिपुटकापसारितं, शुल्बेन शुल्बापसारितं, वेल्लकेन वेल्लकापसारितं, शुल्बार्धसारेण हेम्ना हेमापसारितं ।

Roopasya dvow bhaagaaveka: sulbasya thriputakam
thenaakaarodgathamapasaaryathe thath thriputakaapasaaritham,
sulbena sulbaapasaaritham vellakena vellakapasaaritham
sulbaardha säarena hemna hemaapasaaritham

Alloys of two parts of silver and 1 part of copper is known as triputakam. One part iron and 1 part silver is known as vellakam. One part iron, 1 part silver and 1 part gold is known as vellakapasaritham. One part copper and 1 part gold is known as hemapasaritham.

Archeological studies have shown that silver from Mohanjo daro has a purity 94.5%. Alloy of silver is also described in Sanskrit literature other than Arthasastra: (Rasarnava 12.42.2)

चतुर्थसारं कनकं दिव्यं तन्मातृका समं
Chathurtha saaram kanakam divyam thanmaathrukaa samam

Twentyfive percent gold with silver have the colour of pure gold (Rasarnava 7.56.2)

विक्रियार्थं तु रजतं मात्रा विज्ञायभावयेत्
Vikriyaartham thu rajatham maathraa vijnaayabhaavayeth

For sales purposes the above alloy can be further mixed with silver (Rasarnava 12.49.2)

Detailed study on this subject has been reported in Indian Journal of the History of Science [81].

Mercury : Rasachikilsa is primarily focussed on mercury and its various products. Explanations on mercury can be seen in almost all the Ayurvedic and rasa books. Among the metals discussed in Sanskrit literature, mercury gets prominence. A number of alloys were also prepared using mercury. Mercury when mixed with noble metals give the amalgam, i.e these metals get dissolved in mercury. These amalgams or alloys were

prepared, both for making ornaments and for medicinal purpose. Unlike other metals mercury has an important characterstics. Mercury is a liquid metal which is obtained dierectly by distillation as condensed liquid drops. The technological knowledge of mercury and its extraction is different from that of other metals. Knowledge of mercury definitely goes back atleast to 700 BC, the period of Susrutha because, Susrutha samhita and charaka samhita contain information of this metal. The metal extraction is clearly mentioned as distillation and it is described in Rasaratnakara (37)

दरदं पातनायन्त्रे पातितश्च जलाशये ।

Daradam pathnaayanthre paathithascha jalaasaye

Just like drops of water falls, the mercury drops fall from the distillation equipment. The same is the modern procedure adopted for the production of mercury. Distillation of mercury and its amalgam formation have been described in Rasaratna samucchaya (8.64)

मर्दित पारदस्य यन्त्रस्थितस्य ऊर्ध्वम् अधश्च तिर्यक् निर्यातनं
पातनं संज्ञं उक्तं वंगहि सम्पर्क कञ्चुकघ्नम्

Marditha paaradasya yanthrasthithasya oordhvam adhascha thiryak niryaathanam paathanam samjnam uktham vangaahi samparka kanjukaghnam

When the refined ore of mercury (paradam) is heated in a distillation set up the vapour moving up, down and sides, get condensed and drops are collected, which when reacted with vanga gets solidified.

Mercury ore is heated in the modern process to get the metal vapours. Mercury is amalgamated with gold, silver, and other metals, resulting in the solid alloy formation.

In Rasaratna samucchaya, distillation of mercury has been discussed (3.141,144)

दरदः पातयन्त्रे पातितश्च जलाश्रये तत् सत्वं सुतसंकाशं जायते नात्रसंशयः

Darada: paathayanthre paathithascha jalaasraye
thath sathvam suthasankaasam jaayathe naathrasamsaya:

When distilled its satwa (essence) is relased by cooling with water which is suta or mercury. It has the property of fixing materials.

A commentary on the above lines says that the above statement is for zinc and not for mercury. Since similar distillation method is adopted for zinc also, which resembles technologically mercury production, the statement remains as a scientific fact. But zinc is solid in nature whereas mercury is liquid. The explanation 'on drops' is given it appears that the description is on the distilation of mercury.

Mercury has many other uses, even during olden days. One such line is mentioned in Aryabhateeya by Aryabhatta I in 499 AD in which he has directed the use of mercury for a perfect rotation of the golayantra (globe). The quotation has been given earlier, in the astronomical part of this book. The most important use of mercury and its compounds are for the rasachikisa as a medicine.

Lead: Lead is a blackish flexible metal and solid at normal temperatures. Rasaratna samucchaya (5.171) gives this definition for the lead:

द्रुतद्रावं महाभारं छेदे कृष्णसमुज्वलं पूतिगन्धम् बहिः
कृष्णं शुद्धम् सीसं अतः अन्यथा ।

Druthadraavam mahaabhaaram cchede krushna samujvalam
poothigandham bahi: krushnam suddham seesam atha: anyathaa

Readily fusible, very heavy, having a black and bright appearance on fracture, having off, foetida odour and black extension is naga which is the lead. Lead obtained from the archaeological sites of Lothal has a purity of 99.5% and that obtained from

Mohanjo daro was 99.7%. Quotations given earlier from Arthasastra, refer to various alloys prepared from lead. Thus it can be seen that lead and its alloys were well known, and alloying them with bell metal is mentioned in Bruhatsamhita of Varahamihira (57.1-7) and "An alloy of eight parts of lead, two parts of bell metal and one part of brass has been mentioned by Maya as Vajrasankhata, a metal joining seal".

In Rasaratna samucchaya (3.146) the use of lead and its ore products as hair dye is mentioned.

सदलं पीतवर्णम् गुर्जरिमण्डले अर्भुदस्यगिरे
पार्श्वे जातं मृद्दारश्रृंगकं सीससत्वं जनमुत्तमम् ....
Sadalam peethavarnam gurjaremandale arbhudasyaa gire
paarsve jaatham mruddarasrungakam seesasathvam janamutthamam

Seesa satram or cinnabar (?) was known to occur in two varieties; inferior and super grades, which come from Gurjar province near the Abida mountains, coloured yellow with lamella, yielding lead and for preparing hair tonic.

The use of lead, their oxides and a variety of derivatives for dyes is a common practice now. In Rasarnavam (7.112b) extraction method of lead is thus mentioned while explaining the metallurgical process for tin (described earlier). "....... Similarly lead can be prepared from its ores using bones of elephant". The first part of these lines refers to the reduction of tin oxide (ore of tin) using buffalo bones.

Here too the role of the calcium present in the bone (acts as flux) is to remove the impurities after converting it into slag, calcium silicate. In modern times calcium is directly used as calcium carbonate, oxide etc. for the production of lead.

Zinc : Zinc is an ash coloured flexible, low melting metal. Detailed description of this metal has been given under brass.

Zinc components and its alloys with the copper dating back to 3000 BC, were obtained during excavation. These samples have very specific composition of copper and zinc.

The distillation process of zinc extraction is described in these verses in Rasaratna samucchaya

वृन्ताक आकार मूषायां नालं द्वादशकांगुलं दत्तूर पुष्पवत् च ऊध्
र्वं सुदृढम् शिलाष्टपुष्पवत् अष्टाङ्गुलं च सच्छिद्रम् सास्यात्
वृन्ताकमूषिको अनया खर्परादीनां मृदुनां सत्वमाहरेत्

Vrunthaaka aakaara mooshaayaam naalaṁ dvaadasakaangulam datthura pushpavath cha oordhvam sudruddam silastta pushpavath ashtaangulam cha sacchidram saasyaath vrunthaakamooshiko anayaa kharparaadeenaam mrudunaam satvamahareth

Brinjal shaped crucible is attached with a 12 angula (average diameter of a finger) long tube over it like an inverted flower of dhattura. A hole of 8 angula is made in the tube. This crucible is used for the extraction of satva (metallic Zinc) from soft drug of Kharpara (Rasaratna samucchaya 10.22-23)

A series of such crucibles were arranged in a big heater and the crucibles were connected together. The conical datura flower shaped condensers, converge the vapours during the process of condensation. Thus the solid zinc is obtained when the vapour condenses.

Dozens of zinc crucible furnaces were found in different parts of Rajasthan, many of them, dating back to 3000 to 2000 BC. The Sanskrit lines given above and the observation agree each other. Modern process is also the same, but larger crucibles are used.

In Rasaratnakara (31,32) details of zinc production is given:

मूकमूषागतध्मातं टङ्कणेन समन्वितं सत्वं कुटिलसंकाशं पतते नात्रसंशयः

Mookamooshaagathadhmaatham tankanena samanvitham

satvam kutila sankaasam pathathe naathra samsaya:

There is no doubt that this process yields an essence of metal of the appearance of tin.

Tin prior to purification resembles the metallic zinc. Zinc is like tin and it convertes copper into gold (golden coloured brass). Dr. A. K. Biswas [82] in the Indian Journal of the History of Science, gives the explanation on the composition of different types of brass obtained from the various archaeological sites of the Indus valley civilisations during the Vedic period. Which was produced alloying copper with metallic zinc. Hence zinc metallurgy was known even to the vedic people.

A sheet of zinc was excavated from Agora, a town in Athens, Greece. It has been proved that the metal was taken from Taxila, India. This sheet was produced in the 3rd century BC.

Hundred metre deep mines of South Lode when examined using C^{14} dating studies revealed that, the mine was functioning in full swing in 1260 BC. This mine is situated in the modern Rajpura Dariba area of Rajastan.

It has been explained by the experts that the metallurgy of zinc and related technology was taken to the West from India during the 5th - 6th century BC and further later during the 18th century AD.

There is a history of 'smuggling' the technology of zinc production to the West. The details are well documented. In 1597, Libavius received Indian zinc which he called Indian/ Malabar lead [83]. He was uncertain what it was. Paracelsus in 1616 AD is generally credited to have given the name 'zinc' to this 'Malabar lead'. Large-scale export of metal from India to the West was common during the latter half the 17th century. Detailed study of zinc was reported from Europe only in 1695 by Rosco of Hamburg. He produced the metal from its ore, calamine. In

1751 Postlewayt's Universal Dictionary of trade and commerce has to admit ignorance how zinc was made in the East. showing that till then knowledge on the zinc metallurgy had not reached the West. William Champion of Warmley of United Kingdom experimented and applied for a patent for the zinc metallurgy in 1743. It was found later that Indian knowhow was copied and the patenting plagiriasm was reported with criticism as follows: Champion was notoriously close with details of the Indian process at Zawar mines (in Rajastan), and possibly a third party described the general principle of the process to Champion" and the patent application was reported rejected.

The technology for zinc production was exported from India in a similar way the metals and ores were exported. Many tourists and travellers have played the role of "knowledge carriers".

Beckman a scholar from the United Kingdom has reported that an Englishman has gone to India, the 17th century to discuss the process of manufacture of zinc and returend with details of distillation. Prof. Poster wrote : "A Dr. Lane seems to have smelted zinc at his copper workshop in Sansea as early as 1720 and this was done after visiting Zawar in India"[84]. these writings show that the knowledge of the zinc metallurgy has been transferred from India to the developed nations. The technology might have modified and updated but the essence of discovery is basically remain INDIAN.

Tin: Tin has been discussed in almost all the Lohatantra books as trapu or vanga. Tin alloyed with copper to get bronze has been discussed in the first part of this chapter. Two types of tin exist in nature which are interconvertible with temperature and they are alpha and beta tin. Explanation of two types of tin in Rasaratna samucchaya (5:153-154) is as follows:

क्षुरकं मिश्रकं चेति द्विविधम् वङ्गमुच्यते क्षुरकं तत्रगुणै: मिश्रके न हितं मतं धवलं मृदुलं स्निग्धम् दन्तद्रावं सगौरवं नि:शब्धम् क्षुरवङ्गं स्यान् मिश्रकं श्यामशुभ्रकं

Kshurakam misrakam chethi dvividham vangamuchyathe kshurakam thathra gunai: misrake na hitham matham dhavalam mrudulam snigdham danthadraavam sagouravam nissabdham kshuravangam syaan misrakam syaamasubhrakam

There are two types of tins known as kshurakam and misrakam. High quality tin is known by the name kshurakam and not much accepted one is misrakam. White, soft, flexible, tooth types, dense, without making metallic sound is the Kshurakam and the misrakam is blackish white and clean.

According to the descriptions given, it can be concluded that kshurakam is beta tin and the misrakam is alpha tin. It is in this century that the modern world came to know about the two types of tin.

Excavated samples of bronze were available even from Mohanjo daro and Harappa. The percentage proportion of tin present in bronze alloy was 4.5 to 13.2% and 23 numbers of such articles were excavated from there. Tin metal extration, from the period of the Mohan Jodaro civilization, is existing here.

Rasopanishad is a book written in the beginning of the 11th centruy whose 13th chapter exclusively describes the method of tin extraction. The title of the chapter of Vangastambhana sodhanam which means the production of tin.

Rasarnava a book written in the 11th century gives the extraction process of tin as follows:

महिष्यस्थिचूर्णेन वापात्तन्मूत्रसेचनात् वंगशुद्धम्
भवेदग्नौ नागो नागस्थिमूत्रत:

Maahishyasthi choornena vapaatthanmoothra
sechanaath vangasuddham bhavedagnow naago naagaasthi moothratha:

By the use of powdered bones of buffalo in the crude molten metal and by sprinkling its urine over it, tin is produced and purified (Rasarnavam 7.112)

As explained earlier the addition of the bones, the flux of calcium is obtained which gets reacted with sand, the impurity, to form calcium silicates which can be removed as the slag from molten tin. The organic matter present in the bone acts as carbon source to reduce the oxides of tin, to get refined metal.

The modern tin metallurgy came to be known in Europe only in the 16th century during the period of Agricola [85], whereas the Indian descritpions of the process are centuries older than this period.

Vijay Deshpande has reported a series of scientific studies carried out in tin metal, on the basis of the explanations given in Rasopanishad (Indian Journal of the History of Science)[86]. In the 13th Chapter of Rasopanishad, a series of plant products used as flux and reduction process of tin stone (tin oxide) are discussed. These plant products act as carbon for reducing the tin oxide. Instead of plant products, carbon/coal is directly used in the modern method. All the alloys mentioned in the text were prepared by Prof. Pandey and proved that those explanations are true. A variety of the process are given for converting tin into golden coloured alloys. These alloys are produced using different proportions of mica, copper, silver, mercury, etc.

Product obtained from tin is also described on Rasaratna samucchaya (20-2, 21-1)

वङ्गामहेमसहितं विमलं चान्धमूषितं निर्वहितं कूर्पतुत्थे भवेन्मरतकप्रभम्
Vangaamahemaähitham vimalam chaandhamooshitham
nirvahitham koorpathutthe bhavenmarathaka prabham

Tins with mica and equal amount of gold is placed in a closed crucible along with vimala (a plant product) and roasted. It is accomplished in the koorpathootha to get a material resembling emerald in colour and lustre. Possible elements in this alloy are gold, zinc, copper and some extractive from the crucible. Here the crucible also act as a source of fine components. Tin alloys were obtained from Lothal, Mohanjo daro, Harappa and other archaeological sites, substantiating the knowledge of tin and its alloys.

Gold : In Vedas, frequent use of the synonyms of gold stands as ample proof of knowledge. A variety of gold alloys were also mentioned. Arthasastra describes five types of gold (2:13:31)

जाम्बुनदं शातकुम्भं, हाटकं, वैणवं शृङ्गशुक्तिजं, जातरूपं
रसविद्धाकारोद्गतं च सुवर्ण

Jaambunadam saathakumbham, haatakam
vainavam srungasukthijam, jaatharoopam
rasaviddhaakaarothgatham cha suvarnam

Jambunadam, satakumbham, hatakam, vainavam, srungasuktijam are five names given in the above lines for five types of gold, based on the process or the place from where these gold are obtained and produced.

Minor compositional variation can be possible in processing methodology adopted. Similarly composition can also vary depending on the mineral/used for the gold production which might have resulted in the variation of quality. Gold purification has been explained in Arthasastra (2:13:31)

तपनीयं ज्येष्ठं सुवर्ण सुरागं, समसीसातिक्रान्तं पाकपत्र पक्वं
सैन्धविकयोज्वलितं नीलपीतश्वेतहरित शुकपोतवर्णानां प्रकृतिर्भवति
तीक्ष्णं चास्य मयूरग्रीवाभं श्वेतभंगं चिमिचिमायितं काकणिकः सुवर्णरागः

Thapaneeyam jyeshtam suvarnam suraagam
samaseesaathikraantham paakapathra pakvam saindavi
kayojvalitham neelapeetha svethaharitha sukapotha varnaanaam
prakruthirbhavathi theekshnam chaasya mayoora greevaabham
svethabhangam chimichimaayitham kaakanika: suvarnaraaga:

Different types of gold having various colours mixed with lead and made into sheets, mixed with cow dung cake, sand of Souraśhtra and salt and burnt. This will give the best colour for gold, in bluish white, greenish, dove coloured, etc., as desired. Additions of iron gives many other colours including yellowish black, etc.,

Many alloys of gold for coin making are described earlier in this chapter. One such alloy referred to in Bharadwaja's Amsubhodhini [87] is prepared as follows:

ताम्रषोडशके चुलीताम्रषोडशकं तथा । द्वादशस्वर्णलोहेषु
हिरण्याष्टकमेव च गोदन्तीतालषट्कं च सूतपन्यकमेव च ।
सूर्यकान्तशिलाषट्कमेतान् संयोज्य भागशः क्रमान्माधिममूषायां
संपूर्याथ यथाविधि । कूर्मव्याटिकामध्ये स्थाप्येंगलादिभिः क्रमात्
द्वात्रिंशदुत्तरचतुश्शत कक्ष्योष्णमानतः गालयित्वा यंत्रमुखे तद्रसं पूरयेत्क्रमात्

Thaamrashodasake choolethamra shodasakam thathaa
dvaadasa svarnaloheshu hiranyaashtameva cha
godanthee thaala shatkam cha sootha panyakamevacha
sooryakaantha silaashatkamethaan samyojya bhaagasa:
kramaanmaaghimamooshaayaam sampooryaathaa yathaavidhi
koorma vyaatikaa madhye sthaapyengalaadhibhi kramaath
dvaathrimsaduttharachathussatha kakshyoshnamaanatha:
gaalayithvaa yanthramukhe thadrasam poorayethkramaath

Eight parts of potassium iodide, 16 parts of copper of chulithamra grade, (one of the 16 grades of copper known), 8

parts of gold namely hiranyaka grade one of the 12 grades of gold known 6 part of arsenic sulphide, 5 parts of mercury, 6 parts of quarts in a crucible of tortoise shape and melted at 432° temperature and then pour the molten alloy into the mould......

Detailed study on this carried out by Gore has been published in the Indian Journal of the History of Science [87]. Thus, the golden (and other metallic) alloy preparation is given for different applied purposes too.

Sanskrit literature carry a lot of information on this subject. Many of these alloys and some of these methods might not even have come to the notice of the modern scientists. Hence it is worth-while to peruse into the subject by which one can fetch better and more useful information on metals and alloys.

Thus the evidence on the theoretical and technological metal processing capability existed in ancient India is an important and novel source of 'new old knowledge' to the modern metallugrists and scientists. It is not only a matter of pride but also many new ideas still exist unexplored in these books. Let the modern scientst look into these literature as one among the sources of knowledge to discover and rediscover new products and technologies from ancient treasures.

CONTENTS

Ancient Indian mines, description in Sanskrit on ores and minerals. Metals, ore and metallrgy of silver, copper, tin ores, furnaces and kilns, pure metals, corrosion, alloys, brass, bronze, bell metals, coper, iron, silver, mercury, lead, zinc, tin and gold